MAPPING VULNERABILITY OF SPRUCE-FIR STANDS IN THE NORTHEAST TO SPRUCE BUDWORM ATTACK

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Station Paper No. 21

January 1949

FOREWORD

Once again a spruce budworm epidemic threatens to destroy large volumes of timber in the Northeast. One defense against the budworm is to cut and utilize trees in those stands in which the budworms are most apt to feed and breed. In this report the author presents three practical methods of determining what trees or stands should be cut first.

In working out these methods, the author received assistance from the Penobscot Chemical Fibre Company, the Great Northern Paper Company, and the International Paper Company. They encouraged the project and made available their cruise data and other information. The author gratefully acknowledges the help they gave.

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THE HAZARD: OLD BALSAM FIR

One of the most important phases of spruce budworm[2] control through cutting practices is the logging of highly vulnerable stands in advance of the epidemic. Adjusting logging operations to include such stands will not only reduce directly the amount of tree mortality--and hence wood loss--that timberland owners will suffer; but, more important, it will remove conditions now believed to be most favorable for the development of large budworm populations.

Because fir is known to support more budworm larvae than spruce does, stands with high concentrations of balsam fir are more susceptible to budworm attack. Moreover, because mature and overmature fir are

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[2] The spruce budworm (Archips fumiferana Clem.) is a defoliator. It feeds principally on balsam fir (Abies balsamea Mill.), white spruce (Picea glauca Moench.), and red spruce (P. rubens Sarg.). Epidemics seem to run in 30- or 35-year cycles, the last outbreak having been between 1910 and 1920. At that time, stumpage conservatively estimated at $100 million was destroyed in Maine alone. The current outbreak devastating the forests of eastern Canada now threatens the Northeast.

believed less able to recover after defoliation than spruce or young, fast-growing fir, it is the heavy stands of mature or overmature fir that are most vulnerable to damage.

After the last budworm epidemic Swaine and Craighead[3] analyzed the mortality of spruce and fir. In stands corresponding closely to what we now classify as high, medium, and low hazard they recorded average mortalities of approximately 65, 45, and 18 percent respectively.

It is well to bear in mind that in the State of Maine there are probably about 2½ million acres of high-hazard stands. Moreover, studies made in northern Maine have shown that high-hazard stands on the whole contain much greater volumes than medium- or low-hazard stands. This is evident in table 1, which shows average per acre spruce-fir volumes for different hazard classes.

If the pattern of the previous outbreak should be repeated, a loss of more than 7.5 cords of spruce and fir per acre may be expected on the high-hazard stands. This contrasts sharply with a probable loss of about 3.5 cords per acre on medium-hazard stands and less than 1 cord on low-hazard stands. Thus, the loss on highly vulnerable stands alone could well exceed 16 million cords in Maine.

The annual cut of spruce and fir in Maine covers about 200,000 acres. If all cutting operations could be moved to and confined to high-hazard stands in the next 5 years, it is quite probable, in the event of a severe budworm epidemic, that a saving of more than 6 million cords of spruce and fir would result. Of course, complete diversion of all cutting operations to such stands is not practical; but it does not seem too much to expect that at least half of the annual operations could be so diverted.

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[3] Swaine, J. M., and Craighead, F. C. Studies on the spruce budworm. Canada Dept. Agr. Tech. Bul. 37. 91 pp., illus. 1924.

TABLE 1.-- Relative spruce and fir volumes in stands of different budworm hazard

Hazard class	Spruce	Fir	Total
	Cords per acre	*Cords per acre*	*Cords per acre*
High	7.2	4.7	11.9
Medium	5.8	2.3	8.1
Low	4.1	1.0	5.1
All classes	5.9	3.0	8.9

Before cutting schedules can be set up and logging priorities arranged, so-called high-hazard stands have to be located. It has been recognized from the beginning that an effective salvage program must come from joint initiative on the part of the timberland owners themselves. They, in turn, must know where the greatest threat lies, which stands are likely to die first, and which are relatively resistant. They must also consider the cost of logging each area and balance that cost against the probable loss if the timber were not cut. In some cases inaccessibility will prove to be the deciding factor, even in the face of possible heavy mortality. Once he has before him a map of his holdings showing the size and location of potential danger spots, the timberland owner can begin to plan his pre-salvage and salvage campaigns.

The problem, then, is to work out some method by which the timberland owner can quickly and with reasonable accuracy map his timber stands according to their relative budworm vulnerability. He must be able to pick out, and designate for early cutting operations wherever possible, those pulpwood stands that would be the first to die once the budworm becomes established.

With this in mind, Westveld[4] developed a method for rating the vulnerability of any given spruce-fir stand to budworm damage. Tests

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[4]Westveld, M. A suggested method for rating the vulnerability of spruce-fir stands to budworm attack. Northeast. Forest Expt. Sta. 4 pp., processed. 1945.

have shown that through its use detailed vulnerability maps could be prepared with an expenditure of 10 to 12 man-days per township of 23,000 acres.

However, for a useful tool that large timberland owners can use readily to set up logging priority based on relative expected loss, a method is needed that would take not more than 1 or 2 man-days per 25,000 acres. For practical reasons it seemed desirable to modify Westveld's method to make it faster in application, even though at a slight sacrifice in accuracy. Through a series of studies such a method was developed.

A PLAN FOR LARGE HOLDINGS

This is written with the large timberland owner chiefly in mind. It is in his extensive holdings, ranging in size from 50,000 to more than 2,000,000 acres, that the greatest budworm hazard, as well as the greatest potential loss, lies. It is here also that because of inaccessibility the greatest difficulties of salvage are encountered. It is here that vulnerability maps are needed most.

The large timberland owner will do well to select first for mapping those areas where there is some chance of operating within the next 5 or 6 years. Portions of his holdings where there is no conceivable possibility of operating, or where the cost of operating would be greater than the loss sustained if the spruce and fir were killed, should be disregarded, at least for the present.

For the owner who is faced with a salvage problem covering parts of 15 or 20 townships or more, the sooner the segregation of high-hazard stands can be accomplished on operations maps, the better. Diversion of cutting to highly vulnerable stands should, of course, be started immediately wherever possible.

For such extensive holdings, the recommended procedure for preparing a hazard map is, briefly, as follows:

1. Using timber-management or operations maps, eliminate all hardwood types, recent burns and cuttings, cedar swamps, young second growth (nonoperable), and other stands where cruise plots show less than one-half cord (gross) of balsam fir per acre.

2. Classify the remaining stands into areas of high, medium, and low budworm hazard by grouping cruise plots according to the following scale:

Hazard	Cords of fir per acre (gross scale)
High	4.00 or more
Medium	2.00 to 3.99
Low	0.50 to 1.99

Group no fewer than three plots, and classify no area smaller than 50 acres. In large areas, disregard occasional cruise plots where fir volume is more than or less than that of the class of the surrounding stand.

3. In drawing hazard zone boundaries, use type lines where the two appear to coincide. Use streams and ridge lines as indicators of probable softwood (high hazard) or hardwood (low hazard) sites. When in doubt, refer to cruise sheets and figure hazard higher if the spruce and fir is large and apparently mature, lower if it is small and apparently a young stand. For guidance, see figure 3, p. 17.

A PLAN FOR SMALLER HOLDINGS

For smaller holdings, or where a more accurate delineation of hazard classes is desired, or for a check on tracts mapped as high-hazard by the method described above, a more elaborate procedure can be used, employing a vulnerability formula.

The Formula

As already pointed out, larger numbers of budworms build up on fir than on spruce. Also, older fir are more easily killed than younger, fast-growing fir. Thus vulnerability is the product of the amount of fir and its age--or size. Using these relationships, Westveld developed the formula

$$S = V \times BA$$

in which S is the vulnerability rating; V is the volume of fir per acre, in cords; and BA is the basal area of the average-size fir, in square inches.

Thus, a spruce-fir stand having 5 cords of fir per acre averaging 8 inches in diameter breast high would have a vulnerability rating of 401. This formula, when applied to successive cruise plots, or to per-acre fir stand tables for compartments or other small subdivisions on a forest, permits an evaluation of budworm hazard.

A tentative scale of values was set up, showing degrees of hazard believed to correspond with the numerical ratings:

Hazard class	Vulnerability rating
Low	20 to 99
Medium	100 to 249
High	250 or more

The Method

This formula is applied as follows to develop the map:

1. Eliminate all non-hazard areas from consideration (as in 1., p.5).

2. Using the tally for each cruise plot, compute the basal area, in square inches, of the average fir. This can be done quickly by first preparing for reference a table showing basal area in square inches by diameter classes for different numbers of trees.

3. Multiply this average BA by the gross volume of fir per acre on the same plot, entering the product (vulnerability rating) on the map beside the plot.

4. Classify the stands into high, medium, or low hazard by grouping cruise plots according to the following scale:

Hazard class	Vulnerability rating
Low	20 to 99
Medium	100 to 249
High	250 or more

As in the other method described above, group no fewer than three plots and designate no area smaller than 50 acres as a separate hazard zone, and disregard occasional plots whose ratings are more than or less than the class of those of the surrounding area. Use the same guides as for the first method. Relative degree of hazard can be emphasized by averaging the ratings for individual plots within each hazard zone (fig. 2).

A PLAN FOR THE SMALL WOODLOT

For the small woodlot owner, or the timberland owner whose map and cruise data are inadequate for making a hazard classification by either of the two above methods, a reconnaissance of the area from the ground is the best practical way to segregate the stands most likely to be killed.

The farmer with less than a few hundred acres can size up his woodlot by criss-crossing it several times. With ownerships running into thousands of acres, however, it is best to use a compass and make a rough sketch map as the reconnaissance progresses. In such cases, lines should be run parallel to each other, and preferably not more than one-half mile apart.

Classification by this method should be based largely upon the following guides:

1. Areas representing no budworm hazard.--Pure or almost pure hardwood stands, recent cuttings and burns, cedar swamps, black spruce and tamarack bogs, ledges, cleared land, stunted softwoods at high elevations, pure or almost pure pine stands, young second growth (nonoperable), and any other stands where there is less than one-half cord of fir per acre, except pure spruce stands as noted below.

2. Areas representing low budworm hazard.--Where the fir is rather widely spaced and intermixed with other softwoods and hardwoods, and where it is generally young and vigorous; pure stands of spruce (except large, overmature spruce); and any other stands where there is more than one-half cord of fir per acre but less than 2 cords.

3. Areas representing medium budworm hazard.--Immature, fairly vigorous, pure stands of fir, or mature spruce-fir mixtures with up to 50 or 60 percent fir (not overmature); stands containing large, overmature fir widely spaced or in scattered groups; pure stands of large, overmature spruce if such stands are in excess of

20 acres in extent; any other stand where there are more than 2 cords of fir per acre, but less than 4.

4. Areas of high budworm hazard.--Heavy stands of mature and overmature fir, either pure fir or in mixture with other species where the fir exceeds 50 or 60 percent of the number of trees; pure, dense stands of small but stagnating fir if such stands are of 20 acres or more in extent; mixtures of spruce and fir with large numbers of so-called "spire-topped" fir (large, overmature trees with dense, tapering tops indicative of very heavy seed production) and decadent spruce; and other stands where the volume of fir exceeds 4 cords per acre.

SOME TRIAL APPLICATIONS

The effectiveness of any system of evaluating budworm hazard will depend primarily on the ultimate soundness of the assumption that balsam fir is more vulnerable to budworm attack than spruce. Entomological studies in Canada and in the Adirondacks to date, while not conclusive, indicate that the assumption is a safe one. It can be tested conclusively only by examining stands previously classified by this method, after they have been subjected to a budworm infestation. The relative degree of mortality will refute or support the theory.

But, assuming that the principle is sound, the effectiveness of its practical application will depend also on the speed and reliability with which stands can be classified and mapped. This, of course, could be tested by applying the methods to a number of sample stands.

I. Hazard Map From Field Check

One approach was to classify and map an area from actual observation of stand conditions on the ground, and compare results with a map of the same area made up from cruise data alone. This project was carried out on Willimantic Township, owned by the Penobscot Chemical

Fibre Company, in central Maine. This township embraces about 20,000 acres of forested land.

A two-man crew made a reconnaissance of the tract by running observation lines averaging one-half mile apart, and either between or perpendicular to previously established company cruise lines. Timber-management maps had been provided by the company. Division of the area into types and compartments, and further subdivisions by means of streams, ridge lines, and other topographic features, made it possible to classify and map portions of the area as small as 50 acres without difficulty. The map also showed cruise lines with per-acre volume of fir for each plot.

Rapid evaluation of stands could be made readily from observation since only the balsam fir component of the stand had to be considered, and since no attempt was being made to rate each compartment or type numerically, but merely to classify it as low, medium, or high hazard.

Classification of stands was made largely on the basis of the observer's judgment about the degree to which conditions were favorable for the build-up of a heavy budworm population, and the probable liability of the stand to damage, i.e., killing, permanent weakening, or slowing up of growth rates of spruce and fir. In both considerations the primary elements were density of stocking of fir and its average size. Where there was doubt as to whether a particular stand was low or medium, or medium or high, a tally of fir by diameter classes on several 1/10-acre plots could be made quickly and the actual rating calculated. In some cases--for example, a young, vigorous stand of nearly pure balsam fir--the susceptibility to a budworm build-up may be fairly high, but the resistance of the stand to serious damage is also expected to be fairly good because of the stand's rapid growth.

As the study progressed, it was noted that a fourth classification was needed. In pure or almost pure hardwood stands, brushy areas, recent burns, and cleared areas, there was obviously no hazard since there not only was no fir, but also no spruce; so there could be no conceivable damage. This classification was used in preparing

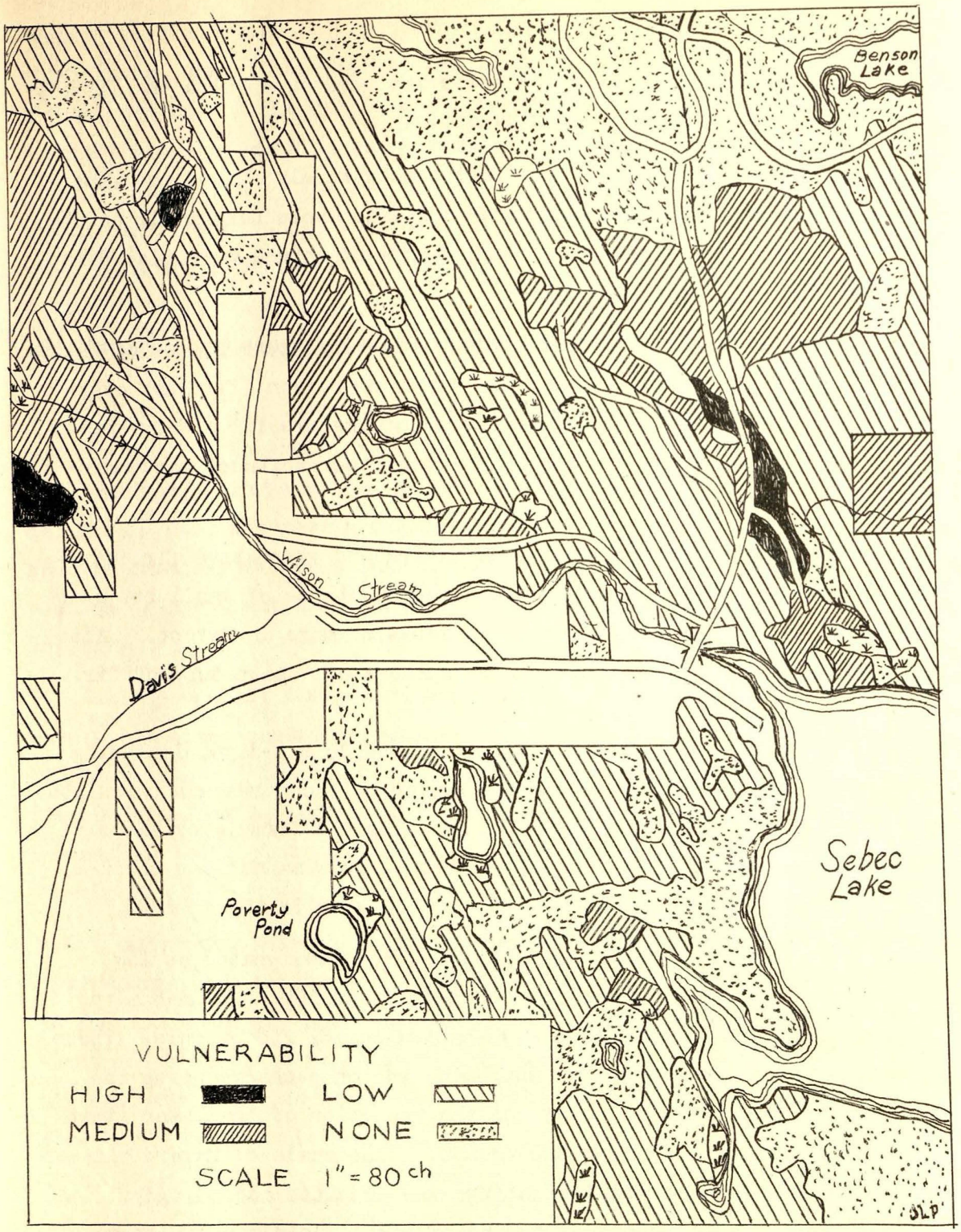

Figure 1.--Budworm vulnerability map for Willimantic Township, Maine. A field survey was used in preparing this map.

the map.

The following descriptive scale was used as a guide in classifying stands by degree of budworm hazard:

Low hazard.--Where the fir was rather widely spaced and intermixed with other softwoods and hardwoods, and where balsam fir on the whole was young and vigorous. Pure stands of spruce were placed in this category.

Medium hazard.--Immature, fairly vigorous, pure stands of balsam fir; or spruce-fir stands with up to 50 or 60 percent fir (not overmature). Also, stands containing large overmature fir widely spaced or in scattered groups, or intermixed with other softwoods and hardwoods.

High hazard.--Heavy stands of mature and overmature fir, sometimes in pure stands. Includes pure, dense stands of small but stagnated fir where such stands are of 20 acres or more in extent. Also, mixtures of spruce and fir with large numbers of "spire-topped" fir.

Following the field survey, which took 26 man-days, including necessary office work, the numerical rating of each area was calculated by using the company cruise data and applying the formula previously mentioned. The hazard rating calculated in this manner was checked against the hazard classification given each area in the field.

In nearly all cases, areas that had been designated as low hazard were found to have ratings between 20 and 100, medium-hazard stands between 100 and 250, and high-hazard stands 250 or more. These are similar to those originally outlined, the only change being the inclusion of a "no-hazard" class and the reduction of the lower limit of the high-hazard class from 300 to 250. The scale of hazard classes and corresponding vulnerability ratings was adjusted accordingly. The final map, almost identical to the original field map, is shown in figure 1.

It is recognized that on a practical basis the time required to

prepare this map might be reduced to 10 man-days by using one man and eliminating some of the office work that was necessary on this experimental project. The question immediately arises, however, about possible means of working out a similar map without the need of putting a man in the field. The advantages of such a procedure are obvious, and attention was turned toward utilizing cruise data that most industrial landowners in the region maintain.

II. Hazard Map From Vulnerability Formula

Parts of two townships owned jointly by the Great Northern Paper Company and the International Paper Company, representing approximately 24,000 acres, were selected for this experiment. This area (T 6, R 10 and T 6, R 11), located in extreme northern Maine, is the south half of what is commonly called Allagash Plantation. For convenience, the portion of the tract that was mapped will be referred to as the Allagash tract.

In preparing the hazard map for this tract, the method was the simple but time-consuming procedure of calculating the actual vulnerability ratings of the 1,005 cruise plots in the tract. From company cruise data showing number of fir by diameter class and gross fir volume[5] for each plot, ratings were computed by means of Westveld's formula.

After the vulnerability ratings had been computed, they were plotted as a map scaled at 4 inches to 1 mile. This map was a tracing of the usual company operations map showing roads, timber types, cruise lines and plots, and topographic features. The plotted vulnerability ratings made a series of lines of entries somewhat similar to level notes of a topographic survey.

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[5]It is essential that net volume, usually given in cruise summaries and representing a certain deduction for cull, be converted to original gross volume, because budworm hazard is just as great (in fact, often greater) for a defective fir as for a sound one.

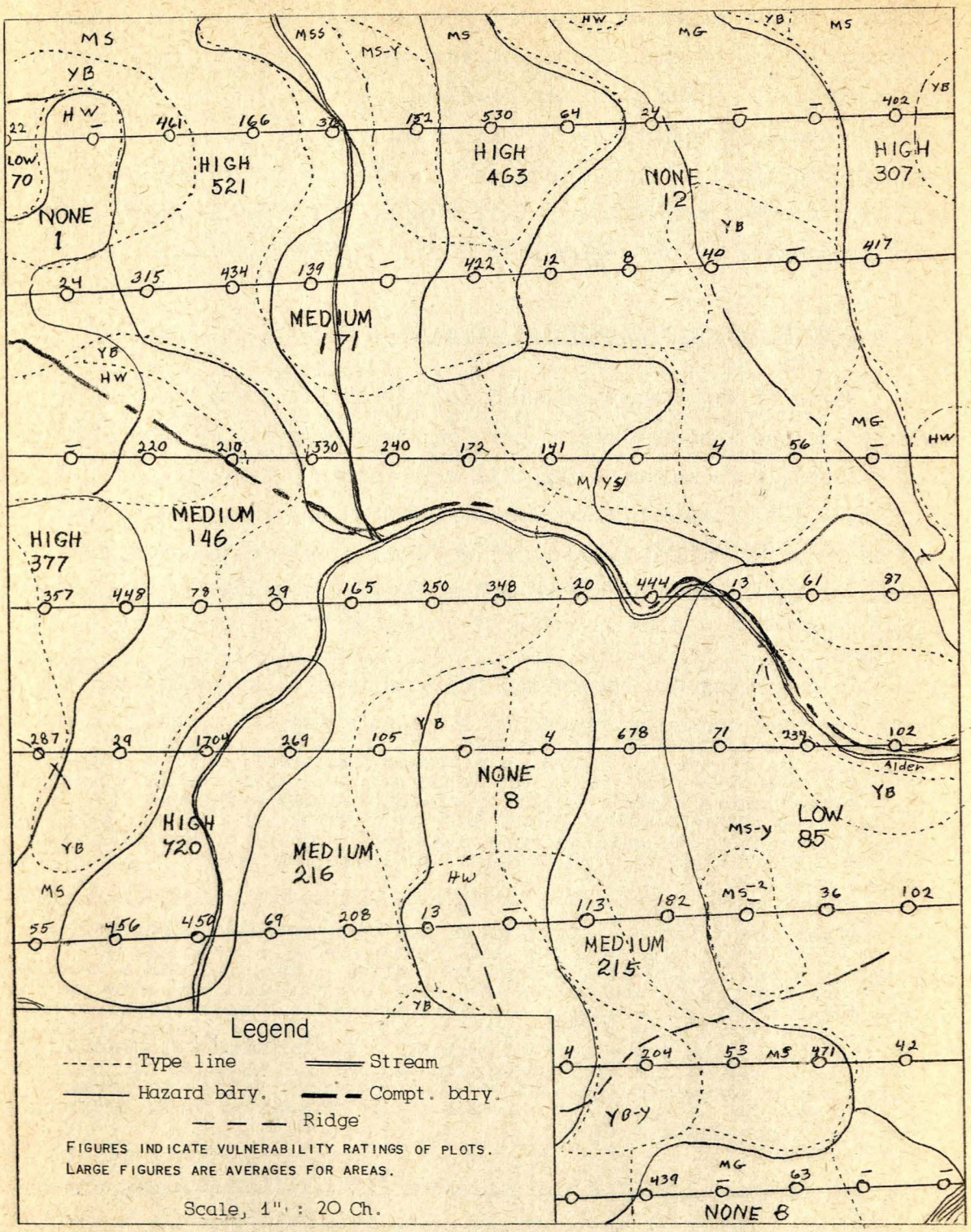


Figure 2.--Budworm vulnerability map showing classification of stands on basis of computed vulnerability rating.

In somewhat the same manner as contour lines are drawn, areas of similar degree of hazard were enclosed. Lines were drawn around groups of plots having vulnerability ratings in the same class--i.e., 0 to 19 for no hazard, 20 to 99 for low hazard, and so on. A small portion of this map is shown in detail in figure 2. No attempt was made to make a hazard zone out of fewer than three plots, and usually no fewer than five or six were segregated. Where large areas, often as large as several hundred acres, were obviously in the same hazard class, individual plots in the area having higher or lower ratings were ignored.

There were some questionable areas where alternating plots along a cruise line or on adjacent cruise lines were in different hazard classes, and it appeared that a stand might well be in either class. In such cases consideration of type lines and topographic features often resolved the matter. If it were a question between medium and low hazard, the stand might be found to lie along a ridge or in an area broadly typed as hardwood. It was then classified as low hazard. On the other hand, if it was found to run heavily to spruce or to lie along a stream, it was given the higher hazard designation. In doubtful cases it was frequently found desirable to check back on the original cruise data of the plots involved. If the stand of spruce and fir seemed to consist of large trees and appeared to be mature or overmature, it was classified at the higher level of hazard. But if the spruce and fir seemed mostly small trees, and the stand apparently young, it was marked down.

In deciding upon the precise course that any line enclosing a hazard area would take, judgment occasionally had to be supported by imagination. Frequently the line logically followed a type line, but as often as not a single type was split into two different hazard zones. In such cases, the lines were drawn half way between cruise plots or cruise lines where the change in hazard seemed to occur. Since cruise lines were a quarter of a mile apart and plots were spaced every 10 chains, more difficulty was encountered in deciding upon the position of boundaries running parallel to cruise lines. However, if significant

signs such as direction of slope, distance from ridge, and position of type lines were carefully observed and considered, the most logical location for the boundary could nearly always be established.

After the boundaries of each hazard zone were delineated, the mean vulnerability rating was calculated by averaging the individual ratings of its component plots. Each hazard zone on the map was then inscribed with its average rating. The finished map can be colored to permit quick appraisal of the hazard situation on the tract as a whole.

III. Hazard Map Based On Fir Volume Alone

The system just described permits classification of forest lands as to probable budworm vulnerability without the necessity of any field check whatsoever. It is, however, a long and tedious process that, even though shortened for a series of townships to 10 or 12 man-days for 25,000 acres, represents considerable expense. Then too, for the company that owns 15 or 20 townships, it would take one man 8 months or more to prepare maps for all the company holdings.

It seemed that some sacrifice of accuracy might be justified if a faster method could be devised. In order to serve as a useful tool with which large timberland owners could quickly set up logging priority in terms of relative potential loss, mapping should not take more than 1 or 2 man-days per 25,000 acres. The experiment was continued along this line, again using the Allagash tract.

Vulnerability ratings for all the 1,005 plots were grouped according to the hazard classes--0 to 19, 20 to 99, 100 to 249, 250 or more. They were then checked against the total gross volume of fir in identical plots. A pattern was quickly observed and it was finally determined that fir volume could also be classified. The volumes corresponding to hazard classes and vulnerability ratings were as follows:

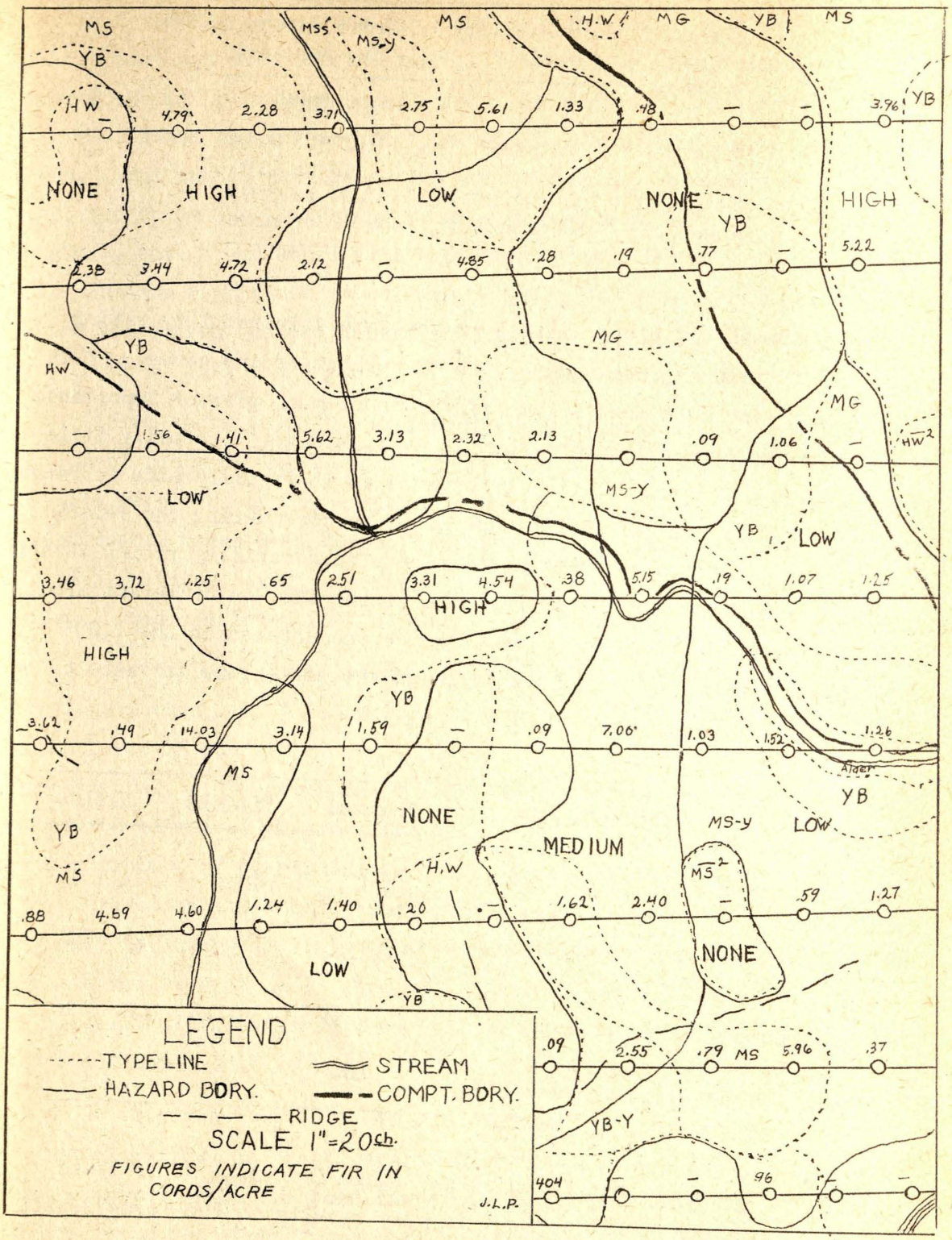


Figure 3.--Budworm vulnerability map showing classification of stands on basis of volume of fir per acre by cruise plots.

Hazard class	Vulnerability rating	Gross volume of fir per acre
		Cords
None	0 to 19	0.00 to 0.49
Low	20 to 99	.50 to 1.99
Medium	100 to 249	2.00 to 3.99
High	250 or more	4.00 or more

Coincidence of plots falling in the same vulnerability rating group and fir volume group occurred in 87 percent of the cases. This would seem to indicate that volume of fir is of much greater importance in determining degree of hazard than is average size. Actually it is not so much a matter of relative importance as it is difference in range of values. This can be readily understood by considering the relative range in values of the two components of the vulnerability rating itself --average basal area and volume per acre of the fir--on different areas. The following tabulation shows the extremes encountered on the 1,005 cruise plots considered in this study, and the difference in ratio of maximum to minimum values.

Item	Maximum	Minimum	Ratio
Average basal area, in square inches	120.1	28.2	4 : 1
Average d.b.h. corresponding to above basal area, in inches	12.4	6.0	--
Volume per acre, in cords	19.81	0.16	124 : 1
Number of trees per acre corresponding to above volume	180	5	--

Thus, the fact that the possible range in number of trees is so much wider than the possible range in size results in the former exerting a much greater influence upon the range in vulnerability rating. This relationship explains and justifies the use of volume of fir alone as an index of budworm hazard.

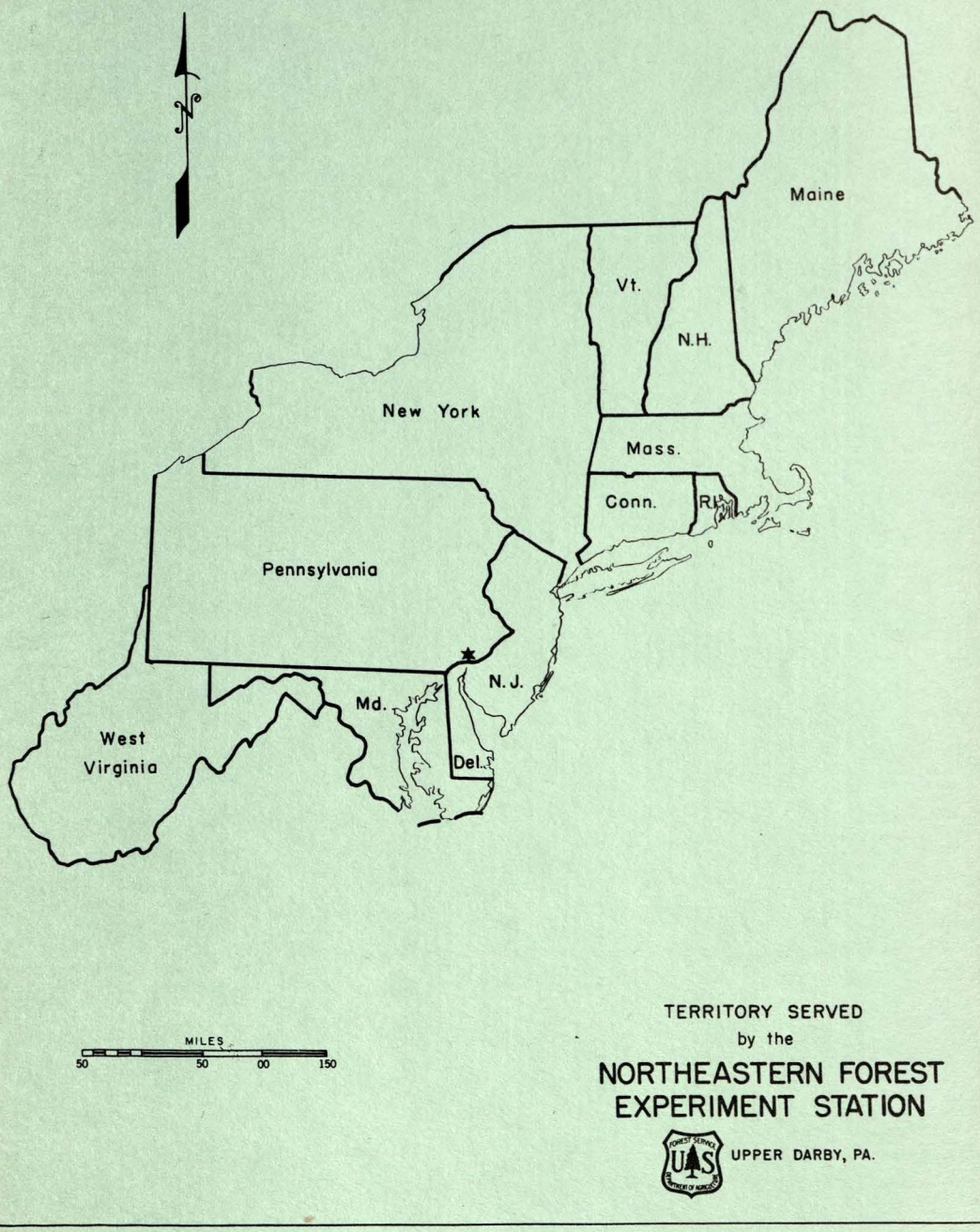
A company operations map showing volume of fir per acre for each cruise plot was used for the test. The scale of fir volume per acre corresponding to budworm hazard had to be adjusted because company records showed net volume after deduction for cull, in this case 25 percent. But rather than raise the volume figures on each plot on the map, the volumes representing budworm hazard were lowered correspondingly so that areas whose cruise plots averaged less than 0.38 cord of fir per acre represented no hazard. Up to 1.5 cords per acre represented low hazard, medium hazard included stands having between 1.5 and 3.0 cords of fir, and anything over 3.0 cords was considered high hazard.

From there on the procedure was the same as that just described: groups of plots having volumes of fir representing similar hazard classes were enclosed by connecting lines. As in the previous method, questionable areas were classified after due consideration of topographic features, type, and stand make-up on component plots. This map (fig. 3) was completed in 1 man-day.

The map was then superimposed on the map prepared with the previous method, and the portions of the two that agreed were outlined and colored in on a third map. This was divided into 12 parts of approximately 2,000 acres each. The amount of colored area was computed and expressed as a percent of the total. The results varied from a minimum of 66 percent agreement to a maximum of 82 percent, and the average for the entire tract was 74 percent. Considering that accuracy is lowered by only 26 percent while time required to prepare the map was reduced by 93 percent, it seems that the shortened system of classification, depending as it does upon volume of fir only, should prove adequate.

It should be kept well in mind that among a number of areas or stands classified as "high hazard" there will be a considerable range in risk involved. In one case there may be 5 cords of fir and 1 cord of spruce per acre; another high-hazard stand may also have 5 cords of fir but 7 cords of spruce. Obviously the latter represents a much greater risk than the former and should be given higher priority in any logging

plan. Once a hazard map has been completed, the high-hazard areas should be scrutinized closely and their relative degrees of risk determined.



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